YEAR 2 FINAL REPORT

Project Period: September 15, 1997 - September 15, 1998

Project Title: Characterization of phytoplankton communities, primary production an detrital components

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Introduction

The Penobscot Bay region has been historically one of the most productive regions of the Gulf of Maine. The area is strongly influenced by the adjacent offshore waters of the Gulf and the products of land and riverine runoff that interact to create temporal and spatial complexity, known to be important in the stimulation of primary productivity which supports all higher trophic levels. At present, there is very little data on the primary productivity, phytoplankton biomass or species diversity in Penobscot Bay. In order to define the carrying capacity of this region, and to identify suitable sites for aquaculture or fisheries restoration, information on the patterns and driving forces of primary productivity are critical. In addition, an apparent enigma exists in Penobscot Bay that sets it apart from other areas of the Maine coast. During the last two decades, most of the Maine coast has been regularly closed to shellfish harvesting due to the presence of the toxin-producing phytoplankter, Alexandrium tamarense. However, for unknown reasons, the area of Penobscot Bay is relatively free of the toxins associated with this organism (Shumway et al, 1988). This phenomenon makes the region even more attractive for shellfish culture and the restoration of clamflats and other shellfish habitats.

Remote sensing of ocean color from both aircraft and satellite platforms has the capability to quantitatively measure upper water column phytoplankton biomass if the signals can be quantitatively interpreted. When coupled with appropriate in situ measurements, remote sensing data can be used to estimate water column primary productivity. For the purpose of ocean color remote sensing, the nearshore waters of the Gulf of Maine are optically classified as extreme case 2 waters. This means that water leaving radiance reaching a remote sensor results from a mixture of optically active substances including phytoplankton chlorophyll, detritus, suspended sediment, and colored dissolved organic

material. To achieve the goal of estimating water column primary production or quantifying accurately chlorophyll biomass for these regions, actual chlorophyll concentration must be determined with a high degree of accuracy, and absorption due to the competing substances must be determined. Considerable ground-truthing of the upwelling radiance must be conducted to correctly isolate and quantify the signal due to the phytoplankton.

The overall goal of this component of the Penobscot Bay Project is to provide the field measurements necessary for accurate interpretation of oceanographic remote sensing data that is associated with primary production. Here we have collected many of the field data required for effective utilization of ocean color and surface temperature imagery. The data include spatial patterns of chlorophyll and primary productivity, the relative contributions of light absorbing compounds, i.e. chlorophyll, suspended particulates, and DOM, and measurement of concurrent hydrographic conditions. These data are required to develop appropriate algorithms for case 2 waters that will be used for more accurate retrieval of coastal chlorophyll concentrations.

Project Summary

1) Field program

The 1998 field effort consisted of four cruises that occurred in March, April, June, and August. The cruise dates were March 27 and 28, April 20 and 21, June 25 and 26, and August 20 and 21. On each cruise, 30 stations were sampled for vertical hydrographic (CTD) data, and chlorophyll concentrations at three depths, to provide broad spatial coverage of the Bay. In addition, nutrient samples were collected at each station and depth for analysis in year 3. At a subset of the stations (6 on the March cruise, 8 on the April cruise, 9 on the June cruise, and 8 on the August cruise), an in-depth characterization was compiled of the phytoplankton community and optical properties of the surface waters. These additional data included in situ light attenuation, photosynthesis vs. irradiance relationships, phytoplankton community structure, both in terms of size and species identification, suspended particulate matter concentration and absorption, and dissolved organic matter absorption.

2) Coordination with other projects

We coordinated the field work with N. Pettigrew (U. Maine), occupying stations sampled by him at previous times. We planned our cruise times to provide better temporal coverage of the area, as well as fill in spatial gaps. Pettigrew and associate participated in the April cruise, collaborating in hydrographic sampling and deploying one of their moorings. In addition, on the March and August cruises, Mark Wells (U. Ca., Santa Cruz) collected water samples for trace metal analyses as part of a separate project with Keller on harmful algal bloom dynamics in Penobscot Bay. Keller and associate also collected sediment samples on the March cruise to map the distribution of resting cysts of harmful algal species. On the August cruise, we also had aboard two scientists from the

laboratory of John Cullen, Dalhousie University, collecting multispectral in situ light data using a tethered light profiling system. These data will give us coincident measurements of water-leaving radiance to compare with the discrete optical data set. This research group will also be collaborating with us on three of next yearís cruises.

3) Sample analyses

At this point, all samples have been analyzed, with the exception of some of the phytoplankton identifications that are still ongoing. The hydrographic and chlorophyll data sets are complete and have been developed into GIS layers and will be submitted under separate cover to Maine Office of GIS (MOGIS) by A. Thomas. The optically-active substances, SPM and DOM, have been measured and compiled into spread sheets. The photosynthesis vs. irradiance relationships have been determined and also compiled into spreadsheet format and graphs. Integrated productivities have also been calculated. These spreadsheets have also been submitted to MOGIS. Phytoplankton cell counts and identifications are continuing and are expected to be completed by M. Keller by the end of the year, when they also will be submitted to MOGIS in spreadsheet format.

Methods

Continuous vertical profiles of salinity, temperature, in situ chlorophyll fluorescence, and beam attenuation (transmission) were measured at each cruise station using a SeaBird CTD, equipped with an in situ fluorometer and 25 cm path length transmissometer. Water samples were collected on the up cast from three depths, roughly corresponding to surface, 10% and 1% incident light levels, using a General Oceanics rosette water sampler and 5 L Niskin bottles.

Phytoplankton chlorophyll and phaeopigments was determined fluorometrically (Parsons et al, 1984) on each of the bottle samples. Triplicate subsamples (100 mls each) were filtered onto a GF/F glass fiber filter, placed in cold 90% acetone, and extracted at -20oC in the dark for at least 24 hours before analysis. Chlorophyll was measured fluorometrically with a Turner-Designs 10-005R fluorometer, modified to give a digital output and calibrated against pure chlorophyll a. Estimates were corrected for degradation products by acidification (Holm-Hansen 1978).

Samples for nutrient analysis were also taken for analysis in year 3. Nutrient samples were collected at the same depths in 20 ml. specially-cleaned plastic vials and frozen at -20oC. Concentrations of dissolved nitrate, nitrite, ammonia, phosphate and silicate will be measured using standard autoanalyzer methodology.

At a subsample of these stations, 3-5 each day, we measured primary production and enumerated, sized and identified phytoplankton dominants. Primary productivity samples were collected after determination of a diffuse attenuation coefficient using a submerged scalar quantum irradiance sensor paired to a deck reference. From the vertical profiles, the diffuse PAR attenuation coefficient was calculated. Photosynthesis as a function of

irradiance (P vs I; PE) was determined using a photosynthetron and 14C incubation (Lewis and Smith, 1983). The P vs. I curves were generated at three, four, or five stations daily during peak light intensity hours (1000-1400 h). The number of samples at each station varied depending on the vertical structure and fluorescence profile of the water column. In general, a stratified water column was sampled at the surface, the chlorophyll maximum or 10% light level, and at the 0.5-1.0 % light level. Well-mixed water columns were sampled at two depths, as they are described adequately by measurements at the surface and 1% light levels. Two ml (March and April) or one ml (June and August) whole water samples were incubated with H14CO3- (200 (Ci) at in situ temperatures and twenty-four different irradiance levels for a 30 minute period. Incubations were terminated by adding 50 (l of formalin to each sample. Residual inorganic carbon was driven off by shaking after acidification with 250 (l of 6N HCl. Light in the incubator was provided by two General Electric ENH projection lamps and filtered through 2.5 cm of water and a 6mm sheet of blue Plexiglass. Irradiances in the photosynthetron were measured with a QSL-100 scalar quantum sensor (Biospherical Instruments, San Diego, CA).

The P vs. I equation of Platt et al (1980) was used to model photosynthesis as a function of light, yielding the instantaneous (Pchl) and maximum (Pschl) photosynthetic rates, normalized to chlorophyll a.

$$Pchl = Pschl * (1-exp((-(chl*E)/Pschl))*exp((-(chl*E)/Pschl)+Pochl \quad (1)$$

Where Pchl is the rate of photosynthesis, normalized to chlorophyll ((g C [g Chl]-1 h-1) at irradiance E ((mol photons m-2 s-1); Pschl (gC[g Chl]-1 h-1) is the maximum rate of photosynthesis in the absence of photoinhibition; (chl (g C[g Chl]-1 h-1 [(mol m-2 s-1]-1) is the initial slope of the PE curve and (chl (g Chl [g Chl]-1 h-1 [(mol m-2 s-1]-1) is a parameter describing the reduction in photosynthesis at high irradiance. Pochl (g Chl [g Chl]-1 h-1) is an intercept term, subtracted from Pchl so that modeled photosynthesis in the dark is always zero. The light-saturated rate of photosynthesis, Pmchl (g Chl [g Chl]-1 h-1) was calculated as:

$$Pmchl = Pschl * ((chl/((chl+(chl))*((chl/((chl+(chl)) \quad (2)$$

With these data and daily surface irradiance data (obtained from RainWise, Inc.(solar-powered products), Bar Harbor, ME), we calculated daily primary production. Total water column production was calculated in a model by integrating photosynthetic rates over depth. Profiles of chlorophyll-specific photosynthesis were calculated from the vertical profile of irradiance and the PE curves:

$$Pchl(z) = Pschl * (1-exp((-(chl * E(z))/Pschl)) * exp((-(chl * E(z))/Pschl) \quad (3)$$

Where irradiance at depth z (m) (E(z), (mol m-2 s-1) is calculated from incident irradiance (E0, (mol m-2 s-1) and the diffuse attenuation coefficient, k (m-1):

$E(z) = E0 * \exp(-k * z)$ (4)

The value of incident irradiance used in Eq. (4) was the mean measured during the determination of the diffuse attenuation coefficient at the time of sampling. Three profiles of Pchl were constructed for each set of samples, one from the PE parameters of each of the three samples. To account for the vertical variation in photosynthetic responses, a weighted vertical profile of Pchl was constructed from the depth-weighted average of upper and lower estimates of Pchl in the interval between each pair of samples (cf. Cullen et al. 1992). Vertical profiles of chlorophyll and productivity (the product of chlorophyll and Pchl) were constructed by linear interpolation between discrete measurements. The product of the vertical profiles of Pchl and Chl was integrated over depth to give areal productivity ((g C m-2 h-1).

$$(= \sum_{z=0}^{z=zm} P(z) * (z \qquad (5)$$

Where (z is 0.5 m. The limit with respect to depth (z = zm) was the depth of the 1% isolume.

Plankton community structure was assessed at each productivity station. Whole water samples (1000 ml) were taken from each depth and preserved with Lugolís solution. A subsample was concentrated using a settling chamber and counted by inverted phase microscopy. Cells (>10 mm) were enumerated and identified to the lowest possible taxon, with special attention given to the identification of the toxic dinoflagellate Alexandrium tamarense. In addition, whole water samples (125 ml) were preserved with paraformaldehyde (0.5% final concentration), refrigerated for several hours, and then subsamples were filtered sequentially through a 8, 3 and 0.2 m? m Nucleopore filter. These filters were mounted on microscope slides, covered with immersion oil and a cover slip and frozen until analysis (Murphy and Haugen, 1985). Chlorophyll-containing cells were enumerated in each size fraction and identified where possible, using a Zeiss Axioskop microscope equipped with epifluorescence illumination.

Other optically-active substances (dissolved and particulate organic matter) were assessed at each productivity station. Samples (100 ml) for the measurement of dissolved organic matter were filtered through a 0.2 m? m filter and stored in sealed dark bottles until analysis. Total suspended particle matter (SPM) samples were collected by filtering 250-500 ml of seawater through a prewashed, precombusted and preweighed GF/F filter, rinsing with 10 ml DIW, and storing the filters, frozen and dark in a clean, numbered plastic petri dish until analysis. The filters were dried at 75oC for 1 h, reweighed and the concentration computed as (W2 - W1)/ volume filtered (Strickland and Parsons, 1972). Spectral absorption (over 350-750 nm) was determined using a Bausch and Lomb Spec 2000 spectrophotometer for both the dissolved fraction (in a cuvette over a 10 cm pathlength) and the particulate fraction, using the SPM filter (before drying) and the filter pad method (Phinney and Yentsch, 1991).

Project results and discussion

Station locations are listed in Table 1. Every attempt was made to sample at slack tide or against the tide so that the same water body was not sampled repeatedly. Stations were chosen from N. Pettigrewís original station grid, and thus, for comparative purposes, these station names were used throughout the cruises. Chlorophyll distributions for each cruise are presented in Tables 2-5 and Figures 1-4). Hydrographic data is not presented in this report, but will be supplied as an additional supplement, and has been submitted to MOGIS, along with the chlorophyll data. In March, chlorophyll biomass was uniformly low, with phaeophytins (degradation products) making up a large percentage of the total. Very low concentrations were observed in the inner Bay and on the west side. A small chlorophyll maximum was observed at St. NP44 on the east side. This was largely composed of the prymnesiophyte, Phaeocystis pouchetii, a springtime phytoplankton known for its large and noxious blooms in other coastal areas. It did not appear to become widespread or very abundant in Penobscot Bay, but its presence warrants further study. In April, the spring bloom of diatoms was well underway, with highest numbers offshore and on the east side of the Bay, although the gradients were not so dramatic between different areas of the Bay. In June and August, chlorophyll biomass remained high and continued to be dominated by diatoms. Surface populations were particularly high, and at inshore locations, populations at depth appeared to be strongly light limited.

Data from the phytoplankton/optical properties stations (Figure 5) begins with vertical distributions of chlorophyll, phaeophytins and total suspended solids for each cruise (Tables 6-9). Suspended particulate matter was uniformly distributed both vertically and spatially in March, but in April, concentrations were very high on the west side of the Bay, especially at the surface. This was probably related to riverine flow. In June and August, the total amount dropped, although there were some very high values at mid-depths in both channels, suggesting subsurface turbulence. Particulate absorption measurements at selected wavelengths for each cruise are presented in Tables 10-13 and absorption due to dissolved organic matter (DOM) at selected wavelengths are presented in Tables 14-17. Absorption due to DOM was much higher at relevant wavelengths (less than 400 nm) than particulate absorption. Values were especially high on the west side in April, again suggestive of riverine influence, and were highest at the surface. Light penetration will be severely curtailed due to the high concentrations of both TSS and DOM.

Vertical distributions of photosynthetic parameters and productivity, as well as values of integrated water column primary production are presented in Tables 18-21. Examples of photosynthesis-irradiance relationships are presented in Figures 6 and 7, with Figure 6 depicting photosynthesis in a well-mixed environment, and Figure 7 in a stratified, light-limited environment. Figures 8-17 examine relationships between some of the measured optical properties (total suspended solids and chlorophyll pigments) vs. absorption at selected wavelengths of light. Ap(400) is often used in algorithms to distinguish particulate absorption. Figures 8-12 demonstrate that in Penobscot Bay, ap(400) is not generally appropriate for this separation. Ap(670) is often used to distinguish chlorophyll absorption. This relationship was much better than that of ap(400), especially when

chlorophyll levels were high (Figures 13-17). Further refinement is obviously necessary as the relationship between the two parameters varies by a factor of two within the entire data set (Figure 17). A seasonal comparison of integrated water column primary productivity between locations within Penobscot Bay is presented in Figure 18. Overall, primary production was higher on the east side of Penobscot Bay (NP40, NP42, NP44) than on the west side (NP7, NP9, NP11, NP 13), although these differences became less apparent in the summer months. The inner Bay was considerably less productive than the areas around and offshore of Vinalhaven Island. Finally, in Figure 19, a comparison of primary productivity vs chlorophyll biomass is examined. The relationship is acceptable, although clearly, it will not be possible to simply predict primary production rates from chlorophyll concentrations.

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